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SEDIMENTARY MEASUREMENT OF CRETACEOUS TIME.[1]

IT is the purpose of this paper to describe certain regular alternations of strata observed in Colorado, to correlate these with an astronomic cycle of known period, and to deduce from this correlation an estimate in years of a portion of Cretaceous time.

Along the base of the Rocky Mountains, and eastward for many miles, the basin of the Arkansas river is occupied by Cretaceous rocks. At bottom are the Dakota sandstones, several hundred feet in thickness; and above these a great body of shales, constituting the Benton, Niobrara and Pierre groups and having a total thickness of 3900 feet. In the main these shales are argillaceous; but at a few horizons they are calcareous, and at one level a sandstone appears, accompanied by a few feet of arenaceous shale. The sandy passage is best developed near the mountains, and disappears altogether toward the east. The calcareous passages are more persistent and have been recognized throughout the district. At least two of them occur many miles farther to the north. As the shales and the associated limestones approach the mountains they do not assume the character of littoral deposits, but remain practically unchanged; and it is thence inferred that the sea in which they were deposited extended to a remote western shore.

[1] Read before the Geological Society of America, December 28, 1894.

The calcareous passages are four in number, and each exhibits a rhythm of sedimentation. The lowest occurs 210 feet above the base of the Benton group, and exhibits an alternation of thin limestone beds with somewhat thicker beds of shale, the shale being more calcareous than the general mass. Each limestone is a few inches in thickness, and the intervening shales are from one to two and one-half feet thick. The average thickness of a pair of beds, including a limestone layer and a shale layer, is eighteen inches, and the number of such repetitions is about fifteen.

Next above are 230 feet of shale, and upon these rest about fifty feet of limestone, constituting the basal member of the Niobrara group. These limestones alternate in an equally regular manner with shales, the layers of limestone being homogeneous and massive, and varying in thickness from one foot to two feet, with three feet as a rare and local maximum. The parting shales range from one to four inches in thickness, and are sharply separated from the limestone. The average thickness of the rhythmic couple, limestone and shale, is as before, eighteen inches.

The third calcareous series, also of Niobrara age, lies ninety feet above the second, the interval being occupied by shale. Through a thickness of thirty feet calcareous shales alternate with those which are less calcareous, and the amount of calcareous matter increases upward, culminating at the top of the series in two beds of chalky limestone. The average rhythmic interval here is between two and one-half and three feet, and the differences in rock texture are of such character as to give a ribbed appearance to the series where exposed on a cliff face.

The fourth calcareous passage is at the top of the Niobrara group, and is separated from the third by 475 feet of shale. It includes several calcareous layers, of which one might be classed as an impure limestone. The rhythmic tendency is clearly manifested, but the number of repetitions is small.

The Pierre shales, overlying these, have a thickness of about 2800 feet.

From these data it appears that, in addition to a secular and

apparently irregular recurrence of physical conditions leading to the disposition of calcareous matter in this district, there was a relatively rapid and remarkably regular alternation of conditions determining the deposition of alternately more and less calcareous matter. The regularity of this minor alternation suggested the possibility that its cause might be discovered, for of the various causes known or supposed to modify sedimentation those which recur with uniform rhythm are comparatively rare. So far as we have definite evidence, the purely terrestrial causes, such, for example, as upheaval and subsidence, the shifting of waterways or divides, and the removal of oceanic barriers, are of irregular sequence; but certain astronomic causes are comparatively regular.

There are many astronomic cycles, and their periods vary widely in extent, but there are only a few to which it is reasonable to appeal for explanation of a rhythm in sedimentation. There are, in fact, but three to which geologists have made such appeal, and my own inquiry has discovered no others. I refer to the period of the earth's revolution about the sun, the precessional period, and the variation of the eccentricity of the earth's orbit. Each of these is known or supposed to have an influence on climates, and the nature of sedimentation may in various ways be influenced by climate.

The period of the earth's revolution does not seem applicable to the sedimentary rhythm under consideration, because a year is too short a time for the accumulation of the sediment. Doubtless eighteen inches of sediment are often added in a year to the sea bottom near the mouths of rivers; but when we consider that many centuries are required to degrade the land to an average depth of eighteen inches, that areas of marine sedimentation are in a broad way commensurate with those of terrestrial degradation, and that the Cretaceous sediments under consideration were accumulated scores and perhaps hundreds of miles from the land, we cannot for a moment imagine that they were deposited at so rapid a rate.

The variation of the eccentricity of the earth's orbit has a

somewhat regular period of about 91,000 years, but the successive maxima are of so unequal values that they cannot well be correlated with the relatively uniform cycles of deposition.

The precession of the equinoxes seems better qualified to explain the Colorado phenomena. As the earth's axis slowly describes its circle on the celestial sphere the relation of the seasons to perihelion is steadily shifted, so that the winter of the northern hemisphere, for example, occurs during one epoch when the earth is nearest the sun, and during another when it is farthest away. The terrestrial consequences of this cycle of change have been discussed by Adhémar, Herschel, Croll, Murphy, Pilar Hill, McGee, Penck, Ramsay, Wallace, Woeikof, Blytt, Ball, Becker and others, and, though there is wide difference of opinion as to the character and amount of the climatic variations which may thus be brought about, these writers are in substantial agreement that the distribution of climates may be materially affected. The precessional period is about 26,000 years, but the position of perihelion also moves—for the most part in a direction opposite to that of the equinoxes—and the resultant of the two motions has an average period of about 21,000 years. It is not absolutely regular, but ranges ordinarily within 10 per cent. of its mean value, and exceptionally to 50 per cent. above and below.

I shall make no attempt to determine what were the climatic oscillations affecting Cretaceous sedimentation in Colorado nor how their influence was exerted. For the purposes of the present discussion it seems sufficient to point out that the local character of sedimentation might be influenced by changes in the local distribution of terrestrial climates:

1. A periodic change in the circulation of the winds might modify the currents of the Cretaceous sea in such way as to bring to this district at one time argillaceous material and at another time calcareous material.

2. A general change of climate producing glaciation about the two poles in alternation, as inferred by Croll and others, might shift the center of gravity of the earth in such way as to

make the sea alternately advance against and recede from a coast. Even a small oscillation of this sort might render the principal load transported by streams from a coastal plain alternately chemical and fragmental; and a great oscillation, by causing the coast line to migrate, might periodically revolutionize the distribution of sediments in the sea.

3. If the climate of a broad peneplain were by precession made alternately moist and dry, then during moist epochs it would be densely clothed with vegetation, subterranean waters would be highly charged with organic acids so as to dissolve much lime carbonate, and mechanical degradation would be impeded by the vegetal mat. During dry epochs vegetation would be sparse, water would have little power of solution, and relatively rapid mechanical degradation would cause the residual clays to be transported to the ocean.

Adopting 21,000 years as the time unit corresponding to each sedimentary alternation in the calciferous portions of the great shale bed, it remains to estimate the rate of deposition of the more argillaceous portions. As already stated, the sedimentary cycle repeats itself every eighteen inches where the principal deposit is limestone; it also repeats itself every eighteen inches where the limestone makes but one-fourth of the total deposit; and it repeats itself in about 2.7 feet where the calcareous material suffices only to modify an otherwise argillaceous shale. It would appear, then, that the shale was on the whole deposited more rapidly than the limestone, so that in the great bodies of shale something more than 2.7 feet of sedimentation should be correlated with a unit of the time scale. It is moreover true that certain portions of the shale are of different type from those associated with the limestone. This difference does not find definite expression in the chemical composition but appeals to the eye. All shales near the calcareous passages are pale gray in color, while there are important beds in the upper and lower portions of the Benton series and in the upper part of the Pierre series which are dark gray. These constitute about one-tenth of the entire series. It is not clear whether we should ascribe

a relatively rapid or a relatively slow deposition to the dark shales, but the fact that the shale body is not entirely uniform in character tends to increase the probable error of an estimate of its rate of deposition. It appears to me that an allowance of four feet of local sedimentation for each astronomic cycle should afford a somewhat conservative estimate for the corresponding portion of geologic time. Upon this basis the 3900 feet of sedimentation required about twenty million years, and this estimate covers the Benton, Niobrara and Pierre epochs. These epochs constitute a part of the Cretaceous period, being preceded in the chronology of the Great Plains province by the Dakota and Comanche epochs and followed by the Fox Hills and Laramie. As the sediments representing those epochs are of different character from the shale to which computation is here applied, the estimate cannot be extended to cover the entire Cretaceous period without materially increasing its probable error.

The reasoning here employed is strictly parallel and partly identical with that of Blytt in his discussion of "The Probable Cause of the Displacement of Beach Lines" (Christiania, 1889). It differs most conspicuously in the interpretation of the influences of dry and moist climates. He correlates fragmental sediments with warmth and moisture, and chemical with coolness and dryness. In discussing the Cenozoic sedimentation of various European countries he finds the alternation of clay and lime carbonate to have an average thickness of 51 inches, nearly three times that observed in the Cretaceous of Colorado.

On the authority of Geelmuyden, Blytt states that the precession period should theoretically have been relatively short in earlier geologic eras because then the axial rotation was more rapid and the oblateness of the spheroid greater; and to whatever extent this was true in Cretaceous time the preceding estimate of twenty million years should be diminished.

That the logic of this discussion may be quite clear, some of its leading points are briefly restated. Certain parts of a shale body are found to exhibit a rhythm of sedimentation, the cycles of

deposition being repeated in from eighteen to thirty-three inches. After making certain allowances, the average unit of deposition for the whole body of shale is assumed to be four feet. From the regularity of the sedimentary rhythm and the large number of its cycles, it is assumed to have been occasioned by a regular rhythm of conditions. The cycle of deposition is correlated with the precession-perihelion cycle—because this alone, of the various cycles known to the writer, appears competent to explain the phenomena. In discussing its competence, the ability of the precessional cycle to produce climatic oscillations is postulated without argument (because it has already been treated at great length by others), and ways are suggested in which climatic oscillations might result in the observed cycle of sedimentation. Assuming that the general inference is valid, the specific estimate is qualified chiefly by the uncertainty in passing from those portions of the sedimentary column where rhythm finds expression in the alternate abundance and scarcity of lime carbonate to the other and greater portions of the column from which lime carbonate is nearly absent. This uncertainty is believed to be represented by the number 2 as a factor of safety; that is, the true period may be either twice or only one-half the estimated period of twenty million years.

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